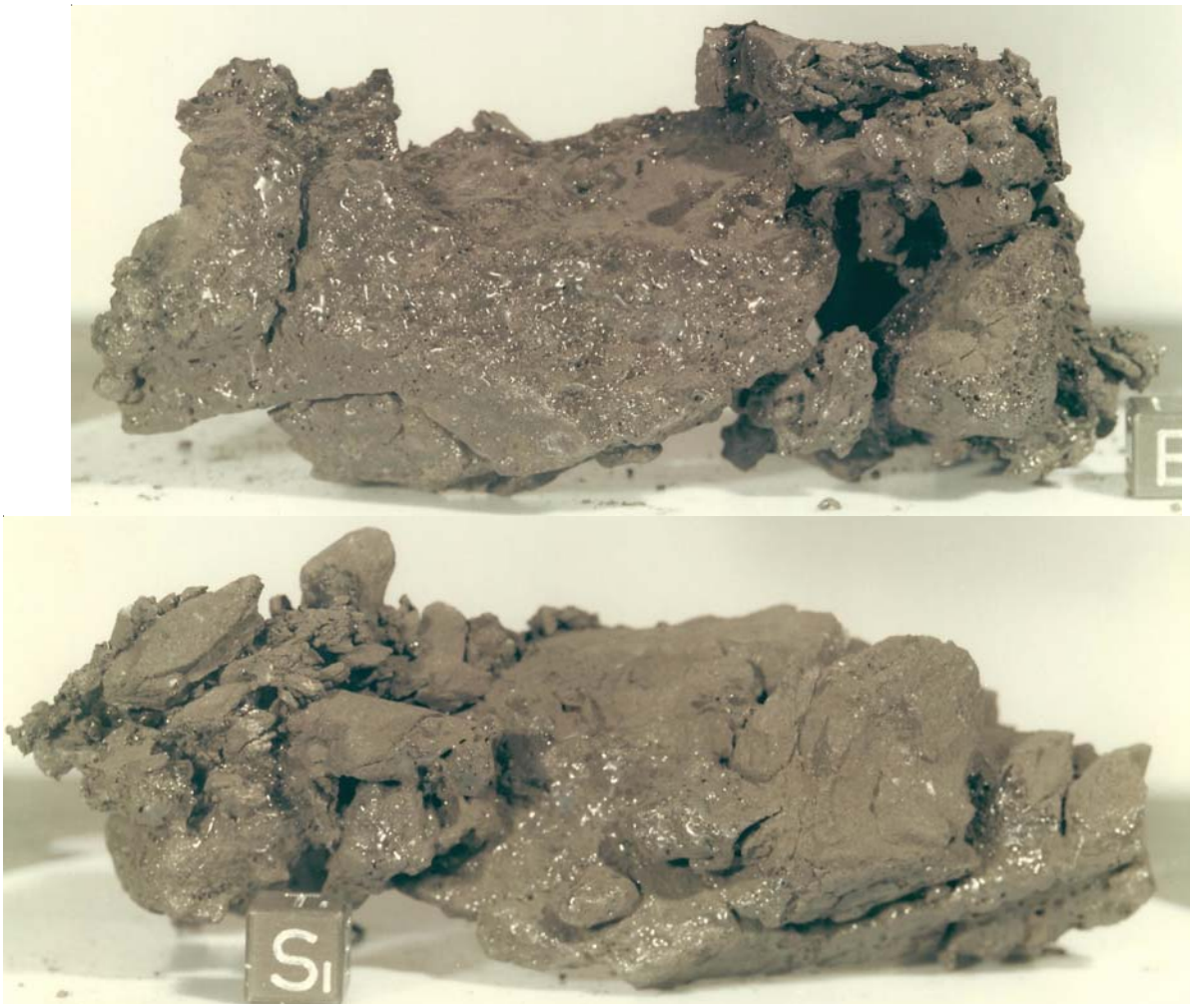
70019

Regolith Breccia

159.9 grams



Figures 1 a,b: Photo of glass-welded mass of soil breccia particles 70019. Cube is 1 cm. S73-15332 and 334.

Introduction

Sample 70019 was collected from within a fresh, 3-meter, glassy-lined crater located near the Lunar Module (figures 2 and 3).

70019 could be consider as an example of a large "agglutinate" made up of pieces of regolith breccia cemented together with black glass (figures 1 a,b and 10).

Note: Numerous investigators (e.g. Greenwood and Heiken 1970; Wilshire and Moore 1974; See et al. 1986) have shown an interest in glass from small, fresh craters in the lunar regolith and it is rather disappointing that they haven't honed their interested by studying this particular large glass object1

Mineralogical Mode for 70019

	(Simon et al. 1990)	
Matrix	59.7 %	
	20-90 micron	90-100 micron
Mare Basalt	1.0	6
KREEP Basalt		
Feld. Basalt		
Plutonic	0.2	0.2
Granulitic	0.2	0.3
Breccia	0.5	1.1
Olivine	0.5	0.1
Pyroxene	10.3	2.5
Plagioclase	3.1	1.0
Opaques	2.1	0.1
Glass	4.1	1.6
Agglutinate	3.8	1.4

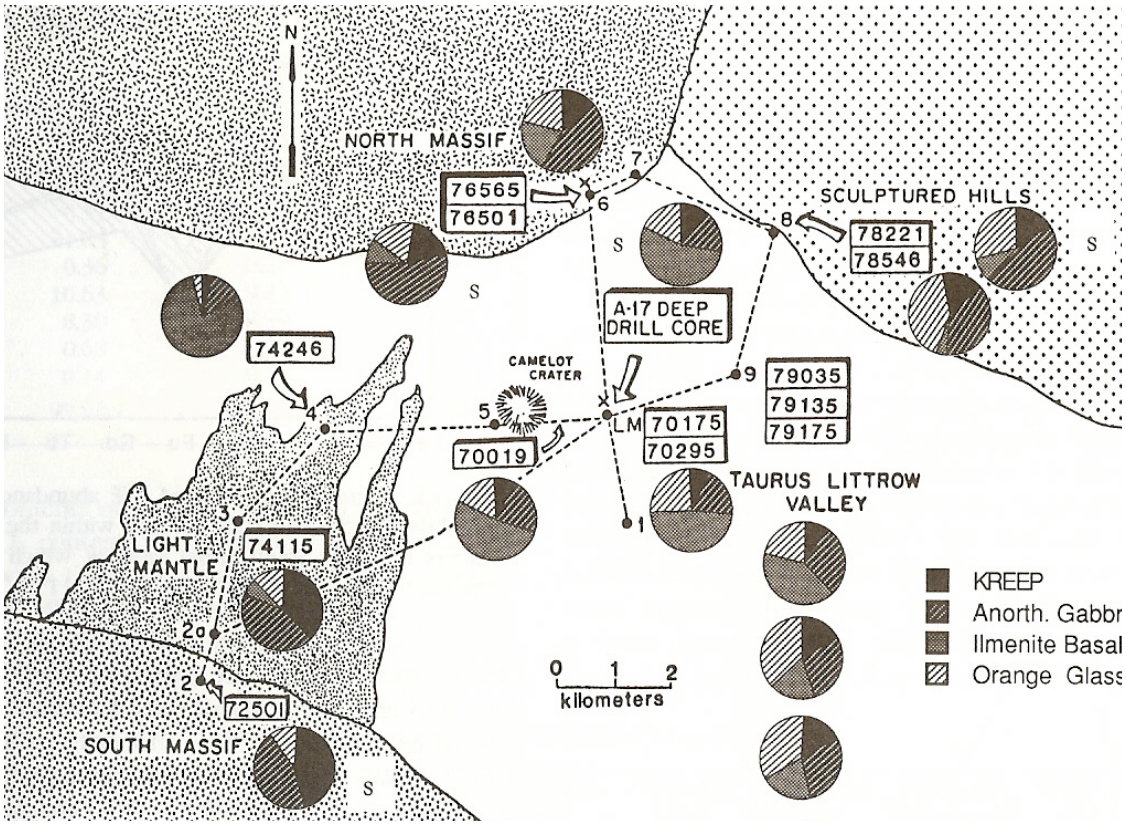


Figure 2: Location of regolith breccias at Apollo 17 site (Simon et al. 1990).

Figure 3: Small (3 m) crater where 70019 was collected. AS17-145-22186.

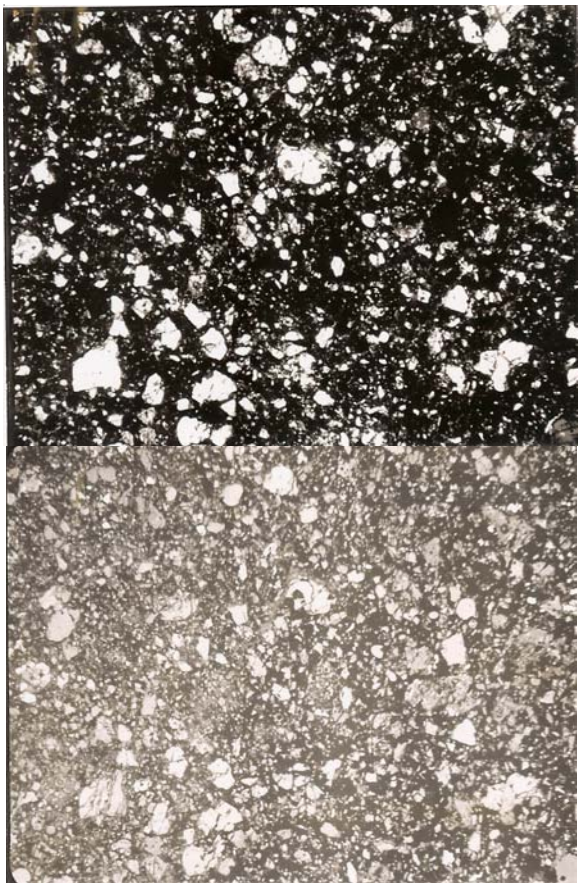


Figure 4: Transmitted and reflected light photomicrographs of thin section 70019,94.

Petrography

Fruland (1983) and Simon et al. (1990) included 70019 in their study of regolith breccias from Apollo. It is made of two major components – dark, coherent microbreccia fragment and black shiny glass. The microbreccia has a seriate grain size distribution with glass matrix and glass inclusions (figure 4 a,b). Simon et al. (1990) found that the matrix was 60% (figure 5) and that agglutinates were abundant (figure 6). Typical orange glass is also abundant. Pearce and Chou (1977) also described 70019.

Glass

The glass in 70019 has been the object of several studies. Fredriksson et al. (1974) and Mao et al. (1975) reported analyses, while Klein and Uhlmann (1976) and Uhlmann et al (1979) used the glass in 70019 to discuss viscosity of molten glass on the Moon. Sato 1976) and Mao et al. (1975) discussed the reduction of iron in glass in 70019.

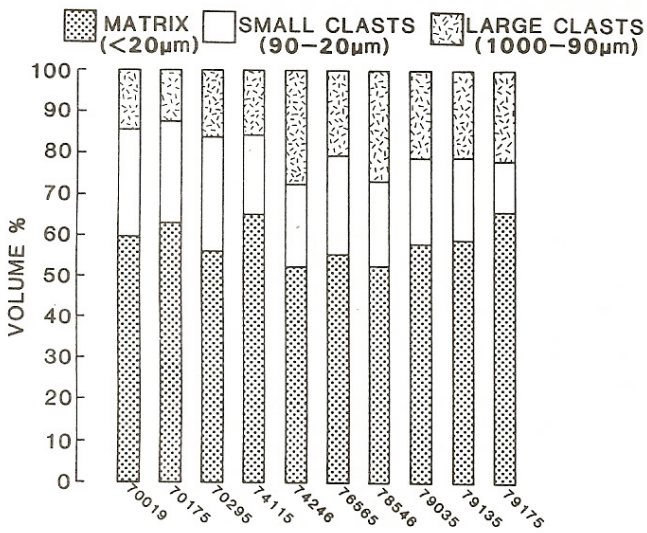


Figure 5: Proportions of clasts and matrix in Apollo 17 regolith breccia (Simon et al. 1990).

Chemistry

Rhodes et al. (1974), Wiesmann and Hubbard (1976), Pearce and Chou (1977), Wanke et al. (1976) and Simon et al. (1090) all obtained similar results (table 1). It has the composition of the soil in the area of the LM (figure 8, 9). Jovanovic and Reed (1975) also reported P, Cl, F and other elements.

Petrowski et al. (1974) determined 142 ppm C, 70 ppm N and 999 ppm S, Norris et al. (1983) reported 116 ppm C and 70 ppm N and Becker and Clayton (1975) reported 60 ppm N (figure 9). Filleux et al. (1977, 1978) reported surface abundances of carbon of ~ 170 ppm. Liech et al. (1974) studied H and F on the surface. It all depends on what part of the sample you study (figure 10)!

Cosmogenic isotopes and exposure ages

Keith et al. (1974) determined the cosmic-ray-induced activity of ^{22}Na = 110 dpm/kg, ^{26}Al = 45 dpm/kg, ^{54}Mn = 166 dpm/kg, ^{56}Co = 240 dpm/kg and ^{46}Sc = 59 dpm/kg. Fruchter et al. (1978) determined ^{26}Al = 52 dpm/kg and ^{54}Mn = 245 dpm/kg. and calculated that this was about 85% saturated.

Other Studies

Nunes et al. (1975) and Church and Tilton (1975) determined U, Th, Pb and Pb isotopes in 70019.

Grossman et al. (1974) showed that the isotopic composition of oxygen in 70019 was on the fractionation line for the Earth and Moon.

Becker and Clayton (1975) and Petrowski et al. (1974 reported an abundance of ^{4}He, but other rare gas studies that could give us the exposure age are lacking.

Sugiura et al. (1979, 1980) studied the magnetic properties of 70019. Pearce and Chou (1977) tried to obtain the direction of magnetic field using the glass, but the orientation of the sample on the lunar surface was not documented. They found that the magnetic properties of the glass were similar to those of the breccias (figure 11).

Processing

There are 12 thin sections of 70019. Most of the thin sections were from only one lithology (figure 10). 70019 was chipped, not sawn.

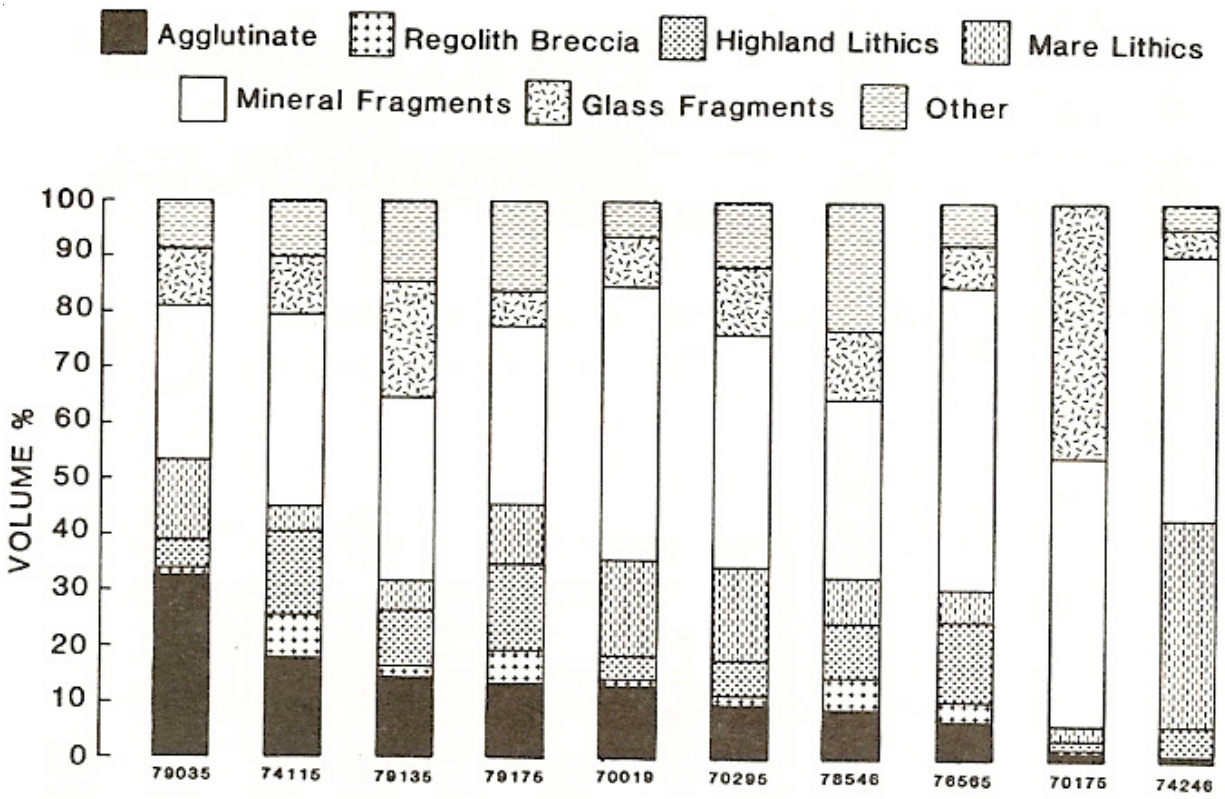


Figure 6: Proportions of lithic clasts in Apollo 17 regolith breccias (Simon et al. 1990).

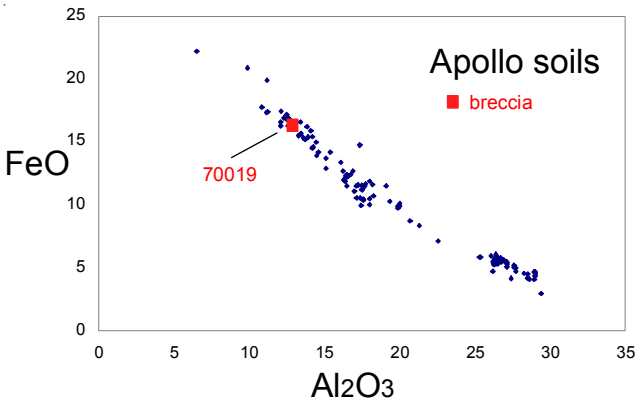


Figure 7: Composition of 70019 compared with Apollo soil samples.

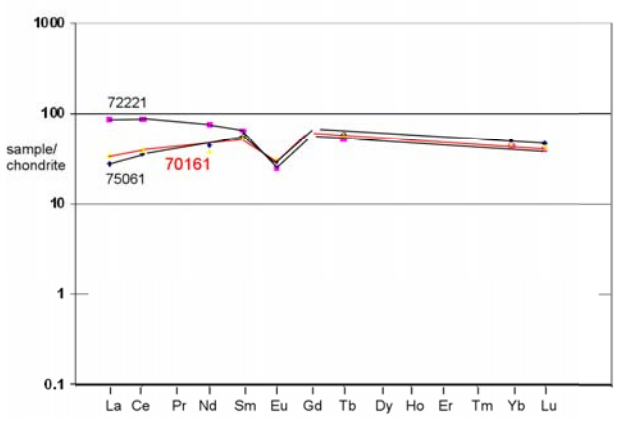


Figure 8: The composition of 70019 is very similar to that of 71061.

Table 1. Chemical composition of 70019.

reference	Rhodes74		Keith74		Simon90		Pearce77		Wiesmann75		Wanke75	
weight							interior					
SiO2 %	40.66	(a)										
TiO2	8.26	(a)			7.91	(c)	8.48	(c)				
Al2O3	12.38	(a)			12.7	(c)						
FeO	16.38	(a)			15.9	(c)	16.7	(c)				
MnO	0.24	(a)			0.219	(c)	0.24	(c)				
MgO	9.5	(a)			9	(c)						
CaO	11.03	(a)			11.8	(c)	11.1	(c)				
Na2O	0.47	(a)			0.41	(c)	0.43	(c)				
K2O	0.09	(a)	0.083	(b)	0.083	(c)	0.09	(c)	0.085	(d)	0.08	(c)
P2O5	0.07	(a)										
S %	0.1	(a)										
sum												
Sc ppm					59.6	(c)	59	(c)			60.4	(c)
V					87	(c)	90	(c)				
Cr	2942	(a)			2870	(c)	3220	(c)				
Co					33	(c)	33	(c)			31.3	(c)
Ni	154	(a)			140	(c)	141	(c)			140	(c)
Cu												
Zn	42	(a)			15	(c)						
Ga												
Ge ppb												
As												
Se												
Rb					2.9	(c)			1.42	(d)		
Sr					170	(c)			170	(d)	200	(c)
Y												
Zr					135	(c)	290	(c)	193	(d)		
Nb												
Mo												
Ru												
Rh												
Pd ppb												
Ag ppb												
Cd ppb												
In ppb												
Sn ppb												
Sb ppb												
Te ppb												
Cs ppm					0.42	(c)						
Ba					97	(c)	105	(c)	95.9	(d)	95	(c)
La					7.9	(c)	8.3	(c)	8.1	(d)	8.44	(c)
Ce					23	(c)	23.8	(c)	23.9	(d)	25	(c)
Pr												
Nd					18.2	(c)	19.9	(c)	21.4	(d)		
Sm					7.61	(c)	8.1	(c)	7.89	(d)	7.87	(c)
Eu					1.6	(c)	1.66	(c)	1.68	(d)	1.7	(c)
Gd					12	(c)			11.5	(d)		
Tb					2	(c)	1.92	(c)			2	(c)
Dy					12.7	(c)	12.4	(c)	13	(d)	14	(c)
Ho												
Er									7.61	(d)		
Tm					1	(c)						
Yb					6.12	(c)	7.3	(c)	6.95	(d)	7.3	(c)
Lu					0.89	(c)	1.05	(c)	0.986	(d)	0.95	(c)
Hf					6.4	(c)	6.9	(c)			6.94	(c)
Ta					1.2	(c)	1.3	(c)			1.25	(c)
W ppb												
Re ppb												
Os ppb												
Ir ppb					4.7	(c)						
Pt ppb					3.3	(c)						
Au ppb												
Th ppm			1.03		0.8	(c)	0.89	(c)			0.68	(c)
U ppm			0.23	(b)	0.2	(c)						

technique: (a) XRF, (b) radiation count., (c) INAA, (d) IDMS

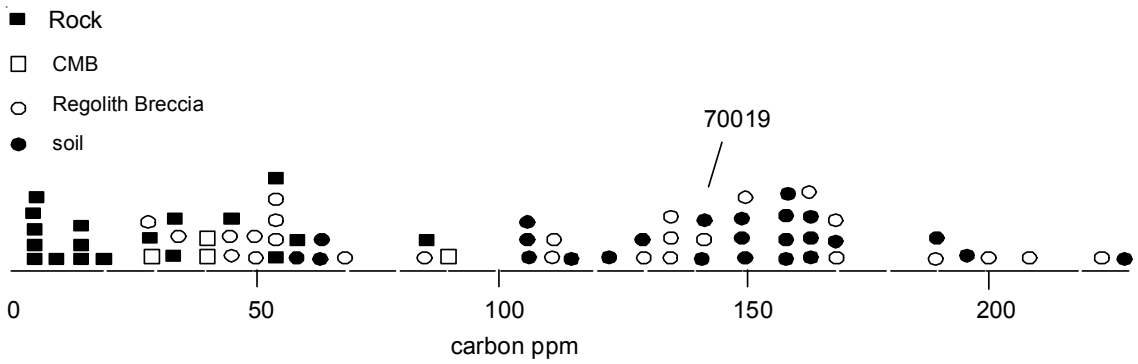


Figure 9: Carbon content of 70019 put in context of other Apollo samples.

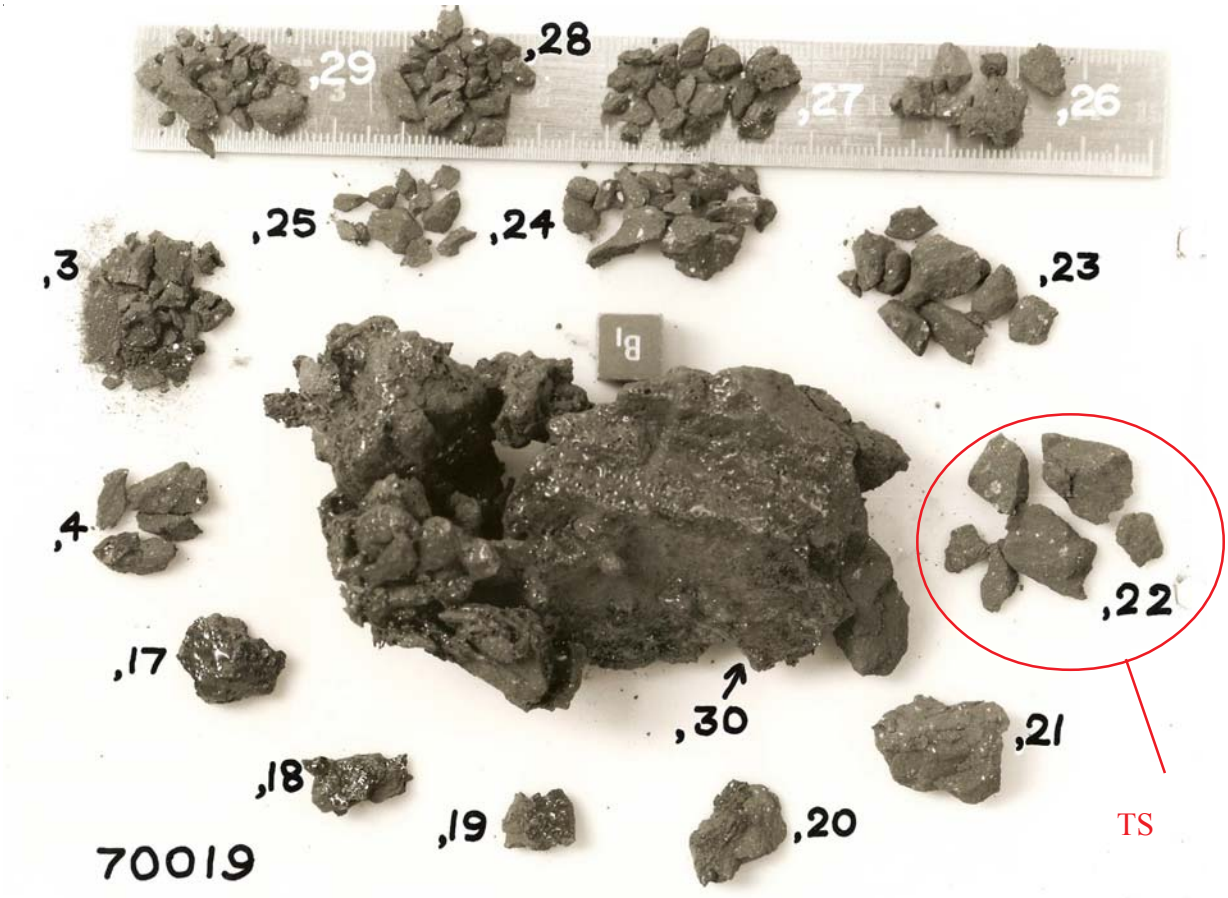
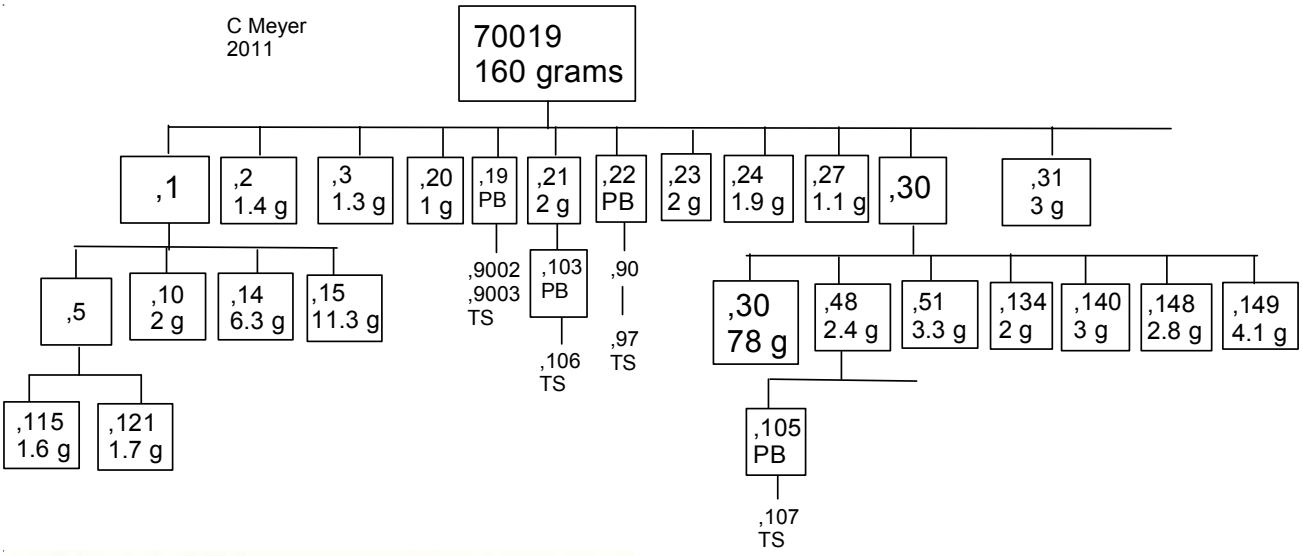


Figure 10: Processing photo of 70019. Cube is 1 cm. S73-37008.



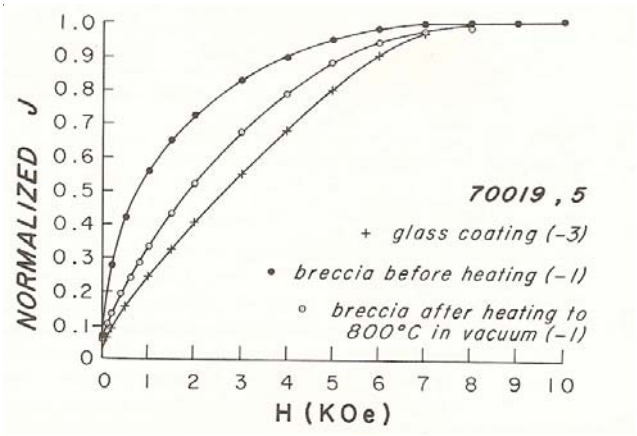


Figure 11: Magnetization curves for glass and breccia in 70019 (from Pearce and Chou 1977).

References for 70019

Becker R.H. and Clayton R.N. (1975) Nitrogen abundances and isotopic compositions in lunar samples. *Proc. 6th Lunar Sci. Conf.* 2131-2149.

Butler P. (1973) Lunar Sample Information Catalog Apollo 17. Lunar Receiving Laboratory. MSC 03211 Curator's Catalog. pp. 447.

Church S.E. and Tilton G.R. (1975) Lead isotope systematics of soils and soil breccias from Taurus-Littrow (abs). *Lunar Sci.* **VI**, 143-145. Lunar Planetary Institute, Houston.

Clayton R.N., Mayeda T.K. and Hurd J.M. (1974) Loss of oxygen, silicon, sulfur, and potassium from the lunar regolith. *Proc. 5th Lunar Sci. Conf.* 1801-1809.

Eldridge J.S., O'Kelley G.D. and Northcutt K.J. (1974a) Primordial radioelement concentrations in rocks and soils from Taurus-Littrow. *Proc. 5th Lunar Sci. Conf.* 1025-1033.

Eldridge J.S., O'Kelley G.D. and Northcutt K.J. (1975a) Primordial and cosmogenic radionuclides in Descartes and Taurus-Littrow materials: extension of studies by nondestructive x-ray spectrometry. *Proc. 6th Lunar Sci. Conf.* 1407-1418.

Filleux C., Tombrello T.A. and Burnett D.S. (1977) Direct measurement of surface carbon concentrations. *Proc. 8th Lunar Sci. Conf.* 3755-3772.

Filleux C., Spear R.H., Tombrello T.A. and Burnett D.S. (1978a) Direct measurement of surface carbon concentrations for lunar soil breccias. *Proc. 9th Lunar Planet. Sci. Conf.* 1599-1617.

Fredriksson K., Brenner P., Nelen J., Noonan A., Dube A. and Reid A. (1974) Comparative studies of impact glasses and breccias (abs). *Lunar Sci.* **V**, 245-247. Lunar Planetary Institute, Houston.

Fruchter J.S., Rancitelli L.A., Evans J.C. and Perkins R.W. (1978a) Lunar surface processes and cosmic ray histories over the past several million years. *Proc. 9th Lunar Planet. Sci. Conf.* 2019-2032.

Fruland R.M. (1983) Regolith Breccia Workbook. Curatorial Branch Publication # 66. JSC 19045.

Graf J.C. (1993) Lunar Soils Grain Size Catalog. NASA Reference Pub. 1265, March 1993

Greenwood W.R. and Heiken G. (1970) Origin of glass deposits in lunar craters. *Science* **168**, 610-611.

Grossman L., Clayton R.N. and Mayeda T.K. (1974) Oxygen isotopic constraints on the composition of the Moon. *Proc. 5th Lunar Sci. Conf.* 1207-1212.

Jovanovic S. and Reed G.W. (1975a) Cl and P_20_5 systematics: Clues to early lunar magmas. *Proc. 6th Lunar Sci. Conf.* 1737-1751.

Jovanovic S. and Reed G.W. (1975b) Soil breccia relationships and vapor deposits on the moon. *Proc. 6th Lunar Sci. Conf.* 1753-1759.

Keith J.E., Clark R.S. and Bennett L.J. (1974a) Determination of natural and cosmic ray induced radionuclides in Apollo 17 lunar samples. *Proc. 5th Lunar Sci. Conf.* 2121-2138.

Klein L., Uhlmann D.R. and Hopper R.W. (1975b) Viscous flow, crystallization behaviour and thermal history of lunar breccias 70019 and 79155 (abs). *Lunar Sci*. **VI**, 481-483. Lunar Planetary Institute, Houston.

Klein L.C. and Uhlmann D.R. (1976) The kinetics of lunar glass formation, revisited. *Proc. 7th Lunar Sci. Conf.* 1113-1121.

Leich D.A., Goldberg R.H., Burnett D.S. and Tombrello T.A. (1974) Hydrogen and fluorine in the surfaces of lunar samples. *Proc. 5th Lunar Sci. Conf.* 1869-1884.

LSPET (1973a) Apollo 17 lunar samples : Chemical and petrographic description. *Science* **182**, 659-690.

LSPET (1973c) Preliminary examination of lunar samples. Apollo 17 Preliminary Science Report. NASA SP-330, 7-1—7-46.

Mao H.K., El Goresy A. and Bell P.M. (1974a) Evidence of extensive chemical reduction in lunar regolith samples from the Apollo 17 site. *Proc. 5th Lunar Sci. Conf.* 673-683.

Mao H.K., E1 Goresy A. and Bell P.M. (1974b) Orange glasses: Reaction of molten liquids with Apollo 17 soil breccia (70019) and gabbro (79155) (abs). *Lunar Sci.* **V**, 489-491. Lunar Planetary Institute, Houston.

Mao H.K., Bell P.M. and Haggerty S.E. (1975) Chemical reduction of glasses in breccia 70019,93: The most reduced Apollo sample (abs). *Lunar Sci*. **VI**, 548-549. Lunar Planetary Institute, Houston.

Norris S.J., Swart P.K., Wright I.P., Grady M.M. and Pillinger C.T. (1983) A search for a correlatable, isotopically light carbon and nitrogen components in lunar soils and breccias. *Proc. 14th Lunar Planet. Sci. Conf.* in J. Geophys. Res. **88,** B200-B210.

Nunes P.D. (1975) Pb loss from Apollo 17 glassy samples and Apollo 16 revisited. *Proc. 6th Lunar Sci. Conf.* 1491-1499.

Pearce G.W. and Chou C.-L. (1977) On the origin of sample 70019 and its suitability for lunar magnetic field intensity studies. *Proc. 8th Lunar Sci. Conf.* 669-677.

Petrowski C., Kerridge J.F. and Kaplan I.R. (1974) Light element geochemistry of the Apollo 17 site. *Proc. 5th Lunar Sci. Conf.* 1939-1948.

Rhodes J.M., Rodgers K.V., Shih C., Bansal B.M., Nyquist L.E., Wiesmann H. and Hubbard N.J. (1974) The relationships between geology and soil chemistry at the Apollo 17 landing site. *Proc. 5th Lunar Sci. Conf.* 1097-1117.

Sato M. (1976a) Oxygen fugacity and other thermochemical parameters of Apollo 17 high-Ti basalts and their implications on the reduction mechanism. *Proc. 7th Lunar Sci. Conf.* 1323-1344.

See T.H., Horz F. and Morris R.V. (1986) Apollo 16 impact-melt splashes: Petrography and major-element composition. *Proc. 17th Lunar Planet. Sci. Conf.* in J. Geophys. Res. **91**, E3-E20.

Simon S.B., Papike J.J. and Laul J.C. (1981) The lunar regolith: Comparative studies of the Apollo and Luna sites. *Proc. 12th Lunar Planet. Sci. Conf.* 371-388.

Simon S.B., Papike J.J., Gosselin D.C., Laul J.C., Hughes S.S. and Schmitt R.A. (1990) Petrology and chemistry of Apollo 17 regolith breccias: A history of mixing of highland and mare regolith. *Proc. 20th Lunar Planet. Sci.* 219-230. Lunar Planetary Institute, Houston.

Sugiura N., Wu Y.M., Strangway D.W., Pearce G.W. and Taylor L.A. (1979a) A new magnetic paleointensity value for a "young lunar glass." *Proc. 10th Lunar Planet. Sci. Conf.* 2189-2197.

Sugiura N. and Strangway D.W. (1980a) Comparisons of magnetic paleointensity methods using a lunar sample. *Proc. 11th Lunar Planet. Sci. Conf.* 1801-1813.

Uhlmann D.R., Klein L., Onorato P.I.K. and Hopper R.W. (1975) The formation of lunar breccias: sintering and crystallization kinetics. *Proc. 6th Lunar Sci. Conf.* 693-705.

Uhlmann D.R. and Onorato P.I.K. (1979) A simplified model for glass formation (abs). *Lunar Planet. Sci.* **X**, 1250-1252. Lunar Planetary Institute, Houston

Uhlmann D.R., Onorato P.I.K. and Scherer G.W. (1979) A simplified model for glass formation. *Proc. 10th Lunar Planet. Sci. Conf.* 375-381.

Wänke H., Palme H., Baddenhausen H., Dreibus G., Jagoutz E., Kruse H., Palme C., Spettel B., Teschke F. and Thacker R. (1975a) New data on the chemistry of lunar samples: Primary matter in the lunar highlands and the bulk composition of the moon. *Proc. 6th Lunar Sci. Conf.* 1313-1340.

Wiesmann H. and Hubbard N.J. (1975) A compilation of the Lunar Sample Data Generated by the Gast, Nyquist and Hubbard Lunar Sample PI-Ships. Unpublished. JSC

Wilshire H.G. and Moore H.J. (1974) Glass-coated lunar rock fragments. *J. Geol.* **82**, 403-417.

Wolfe E.W., Bailey N.G., Lucchitta B.K., Muehlberger W.R., Scott D.H., Sutton R.L and Wilshire H.G. (1981) The geologic investigation of the Taurus-Littrow Valley: Apollo 17 Landing Site. US Geol. Survey Prof. Paper, 1080, pp. 280.